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TAILINGS DISPOSAL

RECOMMENDATIONS FOR SITE SELECTION

1976

POLLUTION CONTROL BRANCH

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Ministry of the Environment

The Honourable
George A. Kerr, Q.C.,
Minister

Everett Biggs,
Deputy Minister

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SUMMARY OF RECOMMENDATIONS

Ontario is a province of abundant land and abundant water. Neither the land nor the water should be abused. However, a mechanism should be available by which both land and water have the potential for intelligent use under a given set of circumstances.

With regard to tailings disposal, dry land tailings disposal schemes generally offer the possibility of maximum environmental control under a given set of conditions. Land-water schemes normally offer a much decreased possibility of control and deepwater schemes, in most cases, offer little possibility of control.

If other than dry land tailings disposal schemes are being considered,the following points should be noted:

A. Deepwater Disposal Schemes

Deepwater tailings disposal schemes involve the direct discharge, at depth, of tailings into a relatively large body of water.

Certain specific restrictions should be placed on the use of deepwater tailings disposal sites:

(i) upon abandonment of the mining operation and/or the tailings disposal site, all deposited tailings should rest considerably below the depth of turbulence caused by surface wave action and should not be in an area subject to scouring by submarine currents.

(ii) the discharge point of a tailings line feeding a deepwater site should be located below the surface of the receiving water and should be below the maximum depth of turbulence caused by surface wave action etc.

(iii) tailings containing mobile coloured slime fractions should not be deposited in deepwater sites.

(iv) tailings containing significant quantities of releasable substances that are regarded as detrimental to human life and/or are regarded as detrimental to aquatic fauna and/or flora should not be deposited in deepwater sites. Such substances include:

ammonia
arsenic
asbestos (chrysotile and/or amphibole)
cadmium
copper
cyanide
lead
mercury
nickel
radioactive materials (e.g. radium, thorium)
toxic organic or inorganic compounds and those organic or inorganic compounds or substances that tend to bio-accumulate.
zinc

B. Land-Water Disposal Schemes

Land-water disposal schemes apply some of the principles of land tailings disposal to a water site. Commonly, a pervious dam is built across a lake or across the mouth of a bay etc., and the area behind the dam is treated as a land disposal site. Normally, as tailings accumulate, the area behind the dam is converted to dry or relatively dry land.

Certain specific restrictions should be placed on the use of land-water tailings disposal sites:

(i) tailings containing significant quantities of releasable substances that are regarded as detrimental to human life and/or are regarded as detrimental to aquatic fauna and/or flora should not be deposited in land-water sites unless:

a) the dam separating the tailings area from the receiving watercourse is impermeable and;

b) the tailings area decant serving the tailings area is directed to a "downstream" facility (preferably on land) for any required chemical and/or physical treatment.

The substances referred to in this item include:

ammonia

arsenic

asbestos (chrysotile and/or amphibole)

(d)

cadmium

copper

cyanide

lead

mercury

nickel

radioactive materials (e.g. radium, thorium)

toxic organic or inorganic compounds and those organic or inorganic compounds or substances that tend to bio-accumulate

zinc.

(ii) tailings containing mobile coloured slime fractions should not be deposited in land-water sites unless effective colour-removal techniques are to be practiced and the general conditions (i)(a) and (i)(b) above have been met;

(iii) the tailings area should be revegetated before being abandoned.

The following technical paper entitled "On Land Or Under Water? : The Tailings Disposal Problem" is based on a talk given by John R. Hawley at the 77th Annual General Meeting of the Canadian Institute of Mining and Metallurgy. The meeting was held in Toronto, Canada, in May, 1975.

The technical paper referred to above has been included here in order to provide some detailed background information on the many variable factors that must be taken into consideration before a reasonable decision can be made with regard to site selection for tailings disposal.

ON LAND OR UNDER WATER?

THE TAILINGS DISPOSAL PROBLEM

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Why do most environmental groups today insist on the land disposal of mine-mill tailings? Are present day guidelines and regulations pertaining to tailings disposal based on hard-core scientific facts or are they largely based on emotional responses to ill-defined questions? Are the claims of modern day environmentalists totally valid?

The question of the proper disposal of tailings has to be seen in perspective. For instance, in the more highly developed countries of the world, the future seems to assume more importance than the present. In these countries we surround ourselves with life insurance, automobile insurance, fire and theft insurance and such things as health and income plans. All are designed to protect us in the future since we all expect to live to see the future. With this expectation we then are motivated to spend our time and money in investigating and improving our waste disposal procedures since most of us realize that any improvements that we make now will enhance our standard of living in the future. For this reason we express genuine interest and concern over the relative differences between "on land" and "underwater" tailings disposal and we expect

the tailings disposal method to be followed which will have the least effect on the environment. For this reason it is appropriate to review and draw conclusions from the various methods of tailings disposal used in the highly developed countries. In the less fortunate countries of the world, - and there are many of these -, an individual's future may well depend on whether or not enough food can be obtained for the day. Under these circumstances, the "present" becomes all-important, the "future" non-existent and environmental control is a luxury that can seldom be afforded. Tailings disposal in these countries may be "on land" or "underwater" but the reasons for the disposal methods being used in any of these countries are generally more highly political and economic than they are environmental. This is not to say that the tailings disposal practices being followed in these countries are inadequate. In many cases, they are more than adequate. It is simply to say that when noting the various methods of tailings disposal being used in different countries, one must always be aware of the circumstances that generated the method of tailings disposal that was adopted. Where tailings disposal is concerned, economic and political factors are of prime importance in <u>any</u> country of the world but, in the highly developed countries, strong environmental overtones often act to modify these factors. In the under-developed countries, political and economic factors, of necessity, tend to dominate.

Generally, only one or more of three types of tailings disposal sites are available to a mining company:

(1) a site that is totally on land

(2) a site that is totally under water

(3) a site that is partially on land and partially under water or in water

One must always realize that, in certain situations, only one type of tailings disposal site may be available. It is usually futile, for instance, to seek an underwater disposal site in an extremely arid region such as a desert. A large mining operation located on a small mountainous island may be hard-pressed to find an adequate land disposal site with the result that underwater tailings disposal looms as the only alternative. Under circumstances such as these, the available disposal site should be used as efficiently as possible with all due regard for the environment.

Major environmental controversies can and often do arise, however, when a mining operation finds itself in the position of having both land and water tailings disposal sites potentially available for use. This situation is common in many countries and is very common in Canada.

When both land and water tailings disposal sites are available, final site selection is based on many factors including:

(a) the cost of transporting tailings from the mill to the disposal site

(b) the quantity of tailings to be generated

(c) the physical, chemical and on occasion, radiological characteristics of the tailings

(d) the cost of preparing and maintaining the tailings disposal site

(e) the presence or absence of legislation pertaining to mining activities in general and to environmental pollution control in particular

(f) the physical and chemical characteristics of the receiving water in the area of the disposal site

(g) the remoteness of the site (distance from major centres of population)

(h) existing uses (by the public, landowners etc.) of the site

(i) the seismic stability of the area

(j) local weather patterns

(k) the local availability of suitable construction materials

(l) the local availability of a trained labour force or a trainable labour force

(m) the local availability of land or water lots at reasonable prices and so forth

The location and development of an adequate tailings disposal area is, in a great many cases, a very complex task. Most of the factors just mentioned are interrelated and have to be examined in some detail:

(a) The Cost of Transporting Tailings from the Mill to the Disposal Site

As in any properly run business, a mining company must minimize operating costs in order to maximize profits. The transportation of tailings from a mill to a disposal site is one phase of a mining operation that does not normally generate profits. Therefore, tailings transportation costs have to be kept as low as possible.

In general, the cost of tailings transportation increases as the distance between the mill and the tailings disposal site (land or water) increases. Therefore, there is a natural tendency for a mining company to locate a tailings disposal site as close to the mill as possible. Theoretically, tailings transportation costs could be essentially eliminated if a mill was located immediately adjacent to its tailings area. If this were the case, tailings would simply leave the mill and discharge directly into the disposal area. The cost of extensive tailings lines and the attendant mechanical facilities such as pumping stations would be largely avoided. The situation rarely arises, however, where an adequate land tailings disposal site is readily available and adjacent to the mill. On the other hand, in specific geographical areas such as northern Ontario, (Canada), it is not uncommon to find a potential underwater tailings disposal site within a reasonable distance of the mill. If necessary, of course, a mill can almost always be located adjacent to its tailings

area simply because a mill is a construction of man that is subject to man's wishes. However, an orebody must be mined where it is found and this in turn creates a problem. If a tailings disposal site is located a significant distance from an orebody, a mill can be constructed at the tailings disposal site in order to minimize tailings transportation costs but this action in turn forces an increase in ore transportation costs to the mill since the mine is now significantly distant from the mill. If, on the other hand, a mill is located close to its orebody and a tailings disposal area is available adjacent to the mill, there is always the possibility, no matter how remote, that mine workings extending beneath the tailings area could be subject to a tailings inrush disaster such as that which struck the Mufulira mine of Roan Consolidated Mines Limited (Africa) in September of 1970 with a loss of 89 lives (ref. 1). Another problem involves the construction of the mill itself. Generally, a mill has to be built on a very secure foundation (usually bedrock) because of the immense loads, stresses and strains imposed by various pieces of milling machinery and reagent and ore storage areas. Thus it becomes apparent that while an orebody is fixed in place by its occurrence, the actual nature and location of a mill and an associated tailings area are actually largely determined by factors such as geography, economics and politics which are uniquely local in character.

It is difficult to generalize as to the relative locations of a mine, mill and tailings disposal area but, normally, a mine and mill are close together and the tailings disposal area (land or water) usually lies within one or two kilometers of the mill. There are, of course, literally hundreds of exceptions to this. Many environmental agencies around the world have developed regulations, guidelines and/or codes of practice relating to the location, design and preparation of tailings disposal areas. This is where a major problem arises. Land or water tailings disposal sites that are considered as "available" by a mining company in many cases may not be considered as "available" by environmental agencies and visa versa. Mining companies will tend to choose a tailings disposal site as close to the mill as possible in order to minimize the cost of tailings transportation. Sites farther away from the mill may be chosen if the cost of site preparation and maintenance is less than that of a site closer to the mill.

As a tailings disposal site increases in distance from the mill, the cost of the tailings line (especially if the line is twinned) increases as do the costs of tailings line maintenance and pumping. Long lines over hilly country may require numerous emergency spill areas that act to receive the contents of the line in cases of emergency (total power failure, mill shut down etc.). In addition, long lines in cold climates have to be heat traced or have to be kept running at specific velocities in order to prevent freezing.

Environmental agencies may deliberately choose a disposal site that is remote from the mill if the use of that particular site results in less damage to the environment than if a specific site closer to the mill was chosen. An agency may also choose a remote land site if the only alternative close to the mill is a water site. Obviously, the agency and the industry in question have to come to an understanding.

The distance that mineral tailings may be transported at almost any mining operation anywhere in the world is normally dependent on economics, availability of materials and political boundaries.

Technology that permits the transportation of wet or dry tailings of varying chemical compositions great distances is presently available. For instance:

(i) Tailings from asbestos operations are normally dry in nature. Belt conveyor systems are used to carry the dry tailings from the mill to the tailings area (a distance that is normally less than 1,000 meters). However, there is one belt conveyor system operating in Spanish Sahara that is 100 kilometers in length. This particular belt system is used to transport approximately 2,000 metric tons per hour of phosphate rock from a mining area to a coastal area (ref. 2).

(ii) Tailings lines made of wood, metal or plastic are common. Mineral tailings are generally transported in a slurry form.

In Ontario (Canada), tailings lines one or two kilometers in length are fairly common and a few lines of greater length are known.

In Japan, one tailings line (31.9 centimeters outside diameter steel pipe) is presently carrying 836,000 litres of 5 to 10 percent tailings slurry per hour. The distance from the mine to the land site being used is 70.6 kilometers (ref. 3). In the Philippines, two tailings lines (one 50.8 centimeters; one 30.5 centimeters outside diameter) are presently carrying a combined total of 31,745 metric tons of tailings per day to an underwater (sea) disposal area. Installed in parallel on common supports, each line is approximately 13,411 meters in length. Associated with these lines are another two (one 45.7 centimeters; one 40.6 centimeters outside diameter) carrying a combined total of 29,476 metric tons of tailings to an underwater (sea) disposal site over a distance of 18,287 meters (ref. 4).

(b) The Quantity of Tailings to be Generated

The selection of a tailings disposal area (land or water) is dependent to a varying extent on the daily rate at which tailings are to be discharged from a mill (or mills if more than one mill discharges to a common disposal area) and on the total anticipated volume of tailings which will accumulate in the area. The disposal problem generated by a mine with a five-year life and a milling rate of 2,000 metric tons per day is obviously quite different from that generated by a mine with a twenty-year life milling at the same rate (in the latter case, tailings storage space has to be provided for an additional 15 years of operation).

In Ontario, an average mill might handle between one and seven thousand metric tons of ore per day during an expected mine life of between five and fifteen years. Larger mines in the Province can provide in excess of 9,000 metric tons of relatively high grade ore per day. To date, tailings areas in Ontario generally cover less than 245 hectares although some in excess of 1000 hectares are known.

In Ontario where fresh water lakes are particularly abundant, tailings from mining operations have been disposed of on land whenever and wherever possible. In a few cases, however, the daily rates of tailings discharge and the total volume of tailings to be stored have been so great that extreme difficulty was experienced in finding large enough tracts of land on which to construct adequate land

tailings disposal facilities. In these cases, a combination of land and water tailings disposal sites have been utilized as the only practicable alternative. Deep water tailings disposal in its truest sense has not been practiced in the Province of Ontario for many years and has never been practiced in the Province on a major scale.

A review of the tailings disposal procedures followed at large mining operations around the world would simply tend to reinforce points already made. For instance:

(i) large or small mining operations located in arid land-locked areas generally have no alternative but to practice the land disposal of tailings

(ref. 5) page 224
Phelps Dodge Corp
Tyrone, New Mexico, U.S.A.
40,815 metric tons tailings/day

(ref. 6) page 283
Magma Copper Company
San Manuel, Arizona, U.S.A.
58,955 metric tons tailings/day

(ii) large or small mining operations located in mountainous terrain near the sea tend to use the sea as a tailings disposal area

(ref. 7) pages 45 to 73
Bougainville Copper
Bougainville Island (South Pacific)
78,000 metric tons tailings/day

(ref. 8) page 512
Utah Mines Limited
Rupert Inlet, Vancouver Island, Canada
5,442,000 metric tons tailings /year

(ref. 4) page 477
Atlas Consolidated Mining
Toledo City, Cebu, Philippines
63,490 metric tons of tailings/day

On a world-wide basis, high grade ore deposits are becoming the exception rather than the rule. As a result, more and more mines are opening up in low grade, high volume orebodies such as the copper porphyries. With primary metal contents of less than one per cent, these deposits give rise to enormous volumes of tailings and waste rock. Under such circumstances, land disposal of tailings becomes extremely difficult especially where the terrain is very mountainous or very flat. In many cases, however, difficult does not mean impossible.

(c) The Physical, Chemical and Radiological Characteristics of Tailings

The physical, chemical and radiological characteristics of tailings vary considerably from mining camp to mining camp.

Very coarse tailings (tailings that will not pass through a 200 mesh screen) generally settle quickly and present minimal problems with regard to either land or water tailings disposal procedures. Very fine tailings (tailings that will pass through a 200 mesh screen) on the other hand can present major disposal problems when either land or water techniques are being used. In addition, coarse or fine tailings disposal procedures can be aggravated by the presence of quantities of highly coloured mineral slimes, quantities of natural minerals that tend to float or remain in suspension and so forth.

A tailings slurry, in simple terms, consists of a liquid phase and a solid phase. The liquid phase is generally predominantly water in which various milling reagents and related chemicals are entrained. The solid phase consists predominantly of gangue mineral particles and includes ore particles that were missed by the milling process.

Toxic or undesirable materials such as mercury, cadmium or radium may occur in releasable forms in either the liquid phase or the solid phase of the tailings slurry. If present, such substances could preclude the use of specific water and/or land tailings disposal sites.

(d) The Cost of Preparing and Maintaining the Tailings Disposal Site

The cost required to prepare and maintain a land disposal site for tailings deposition is generally significantly different than that required to prepare a water site. In fact, in a great many cases, the difference in cost is startling.

If a potential land site and a potential deep water site were located equal distances from a mill, tailings transportation costs to each site would be approximately the same assuming that the terrain in the area was relatively uniform in nature. In general, no significant preparation or maintenance would be required at the deep water site but, at the land site:

(i) the site itself may have to be cleared

(ii) tailings dams may have to be built

(iii) decant facilities may have to be constructed

(iv) dams may have to be raised on occasion

(v) abandoned sections of the tailings area may have to be stabilized

(vi) a trained work crew may have to be on hand at all times to ensure the integrity of the area

(vii) waste treatment of the effluent from the area may have to be arranged --- and so forth

It is not surprising, therefore, that many mining companies around the world pump tailings slurries great distances in order to achieve underwater disposal of tailings and it appears that most mining companies, when given the opportunity, would prefer to use water sites rather than land sites.

(e) The Presence or Absence of Environmental Legislation Pertaining to Mining Activities

The environmental laws of various nations differ considerably. Substances that are regarded as harmful or toxic in one country may be ignored by another country for a variety of reasons. Even within the boundaries of a particular country, environmental requirements may vary considerably according to local or regional jurisdictions.

In general, a mining operation must adhere to local codes of practice, guidelines and/or regulations in order to minimize friction that could develop between the company and local authorities and the local populace.

There are many countries in which land needed for vital food production is too valuable to be used for tailings storage. There are also many countries in which water is too valuable to be used as a sink for tailings. In cases such as these, there is generally no alternative for a company but to follow the directives of the designated agencies or authorities. In countries such as Canada that are blessed with abundant land and abundant water, neither the land nor the water should be abused. A mechanism should be available, however, by which both land and water have the potential for intelligent use under a given set of circumstances.

(f) The Physical and Chemical Characteristics of the Receiving Water in the Area of the Disposal Site

Broadly speaking, there are two basic types of receiving waters to which tailings or tailings wastes are directed:

(1) fresh (sweet) water

(2) salt (sea) water

Within each of these two categories, the variations in overall chemical composition can be rather great. However, typical fresh water differs from typical salt water in a physical sense, in a chemical sense and in life support capabilities.

	Fresh Water World Average ppm (except pH)	Fresh Water Northern Ontario ppm (except pH)	Common Sea Water ppm (except pH)
pH	6 to 7 common	6 to 7 common	8.0 to 8.4
Cl^-	7.8	1	18,980
Na^+	6.3	2	10,556
K^+	2.3	1	380
Mg^{++}	4.1	1	1,272
Ca^{++}	15	7	400
$SO_4^=$	11.2	7	2,649
Total Dissolved Solids	120	50	35,000

(ref. 9)
(ref. 10)

Salt water is alkaline in nature while fresh water is commonly neutral with a tendency towards slight acidity. Fresh water is characterized by a low total dissolved solids concentration. The seas are known for their great areal extent, their great volume, their great diversity of life and their nutrient richness. Fresh water on the other hand is known for its erratic distribution, its scarcity on a global basis, its occurrence in bodies of limited areal extent and limited volume, its restricted diversity of life, its extreme sensitivity to its environment and, in relative terms, its general lack of nutrient richness.

From a physical and chemical standpoint, it is logical to suspect that many types of mineral tailings will react differently when placed in contact with sea water than when placed in contact with fresh water. For this reason, it is difficult to equate salt water tailings disposal procedures with fresh water tailings disposal procedures and, in general, they should be recognized as totally different procedures being used for different reasons and producing different effects. The actual physical mechanisms of tailings disposal, however, are quite similar for tailings disposal to both fresh and salt water bodies. Therefore, a number of environmental effects produced by tailings disposal to a body of water are shared by salt and fresh waters alike. In addition, both sea water and fresh water normally contain extremely low concentrations of the metals etc., that are regarded as toxic to aquatic life. Many of these toxic substances are found in various forms in mineral tailings.

(g) The Remoteness of a Tailings Disposal Site (distance from major centres of population)

A mine located in a remote region has to face problems that arise because of the isolation factor itself. For instance, transportation to and from the site may be difficult and expensive, broken equipment sometimes cannot be quickly replaced or easily serviced, skilled workers

may be difficult to find and to keep on the site and relatively cheap energy sources may not be obtainable. Under these circumstances, mining, milling and tailings disposal procedures are generally kept as uncomplicated as possible. While underwater tailings disposal probably represents the least complicated form of tailings disposal, environmental agencies in developed countries do not as a rule favour this procedure and therefore, even in extremely remote areas, a potential underwater tailings disposal site may not be available to a company unless suitable land sites are totally unavailable. Because the public as a whole is very dependent on good quality sources of drinking water, on foodstuffs obtained from water and on the recreational pursuits provided by water, land disposal of tailings is very common in and near areas of high population density. Underwater disposal is rare in these areas.

(h) Existing Uses of Potential Tailings Disposal Sites

Existing uses of a potential tailings site can be a major factor in determining whether land or underwater procedures may be followed. In some cases, existing uses of an area may be sufficiently important to preclude the underwater disposal of tailings, to preclude the land disposal of tailings and, possibly, to preclude mining altogether.

Possible existing uses of a potential land or water tailings disposal site could include the following:

(i) the site could be an important source of food (shellfish, fish, aquatic vegetation etc) for the local inhabitants of the area

(ii) The site could support an important sport fishery

(iii) the site could be an important spawning ground for a specific species of fish etc.

(iv) the site could be an important breeding ground for specific land-animal species

(v) the site could encompass rare land forms

(vi) the site could support populations of rare or endangered plants and/or animals

(vii) the site could be within a national park, a public park or within reserve lands

(viii) the site could be dangerously close to public or private dwellings, military installations or airports etc.

(vix) the use of the site could interfere with public or private roads, railroads, hydro-electric installations or could interfere with access to other areas and so forth

(i) <u>The Seismic Stability of the Area</u>

In areas prone to earthquakes and the resultant ground motion, it is not advisable to attempt massive land

tailings disposal schemes unless all dams are adequately engineered and are specifically designed to withstand the periodic shocks produced during a major earthquake.

(ref. 11, pages 325 to 355)

(j) Local Weather Patterns

Local weather patterns to a great extent influence the final design and characteristics of both land and water tailings disposal systems. The maximum impact of local weather patterns, however, is on land disposal systems.

In Ontario (Canada), for instance, long winters normally result in large accumulations of snow and ice on land disposal areas. Warm spring weather melts these accumulations in a relatively short time which often results in flooding conditions. Most land tailings area failures in Ontario occur during this period. As a result, land tailings areas in Ontario must be engineered in a manner that promotes maximum stability and hydraulic integrity at all times and especially during spring runoff.

While flooding problems are sometimes difficult in Ontario, they cannot compare to problems experienced in countries like India where, during the monsoons, 56 centimeters of rain have fallen in 24 hours. The typhoons of east Asia are known for the precipitation and the winds that they generate. Damage to man-made structures is sometimes great.

Land tailings areas built in the Arctic generally lie on perma-frost which tends to be unstable. Tailings lines may freeze --- and so forth.

It is obvious that many of the tailings disposal problems that are due to weather could be solved by utilizing underwater tailings disposal procedures.

(k) The Local Availability of Suitable Construction Materials

One major problem with regard to land tailings disposal areas is the local availability of suitable construction materials. This problem can be very serious on level land since the tailings area must be totally confined by massive man-made perimeter dams. The problem can be less serious in hilly country where only short dams may be required. If natural clays are not available, extreme difficulty can be experienced when one attempts the construction of impermeable dams. In other cases, local material may be completely unsuitable for stable dam construction.

Dams etc., are generally not required for underwater tailings disposal.

(l) The Local Availability of a Labour Force

Assuming that tailings transportation distances are approximately equal and that the terrain over which the transportation takes place is similar, an underwater

tailings disposal site generally does not require the labour force that is required by a land disposal site. A land disposal site, however, does require constant maintenance if failures are to be averted.

If an adequate labour force cannot be secured, underwater tailings disposal may be desirable from a company standpoint.

(m) The Local Availability of Land or Water Lots

A potential land or water tailings disposal site may not be available to a company if the company cannot obtain jurisdiction over or ownership of the land or water site in question. In some cases, a particular land site may be for sale but at unreasonable prices. If this is the case, the company has no alternative but to pay the price or to seek another land or water site.

From the foregoing it should be obvious that, under a variety of circumstances, land disposal of tailings is either uneconomical or physically impossible. Under other circumstances, underwater tailings disposal is uneconomical or physically impossible.

There are, of course, situations in which both adequate land and underwater tailings disposal sites are simultaneously available. It is best, therefore, to discuss the advantages and disadvantages of both land and underwater tailings disposal:

(A) The Advantages of a Dry Land Tailings Disposal Site

(1) All solid tailings are retained on land. Watercourses etc., are not inundated with tailings particles.

(2) Since a tailings mass is readily accessible on land, complete physical and chemical control is possible within the bounds of technology.

(3) The aqueous phase of a tailings slurry is decanted from a land tailings area. This permits control, within the bounds of technology, of the toxic components of the aqueous phase of the tailings slurry.

(4) In many cases, tailings area decant water can be re-used in the mill. This limits the mill requirements for virgin water.

(5) A properly maintained land tailings area confines the solid tailings within a well-defined area.

(6) In most cases, abandoned land tailings areas can be stabilized by vegetation. If properly carried out, revegetation procedures can convert an abandoned tailings area into an indistinguishable part of the local countryside.

(7) Mineral tailings are frequently reworked for their residual mineral content. If care is taken, a land tailings area can be reworked with little disruption of the environment.

In essence, maximum environmental control is possible, within the bounds of technology, at a dry land tailings disposal site.

(B) The Disadvantages of a Dry Land Tailings Disposal Site

(1) A properly designed land tailings disposal site can be very expensive to construct, operate and maintain. This is the main disadvantage of a land disposal site.

(2) The failure of a tailings dam is always possible no matter how improbable. Tailings dam failures can result in loss of human lives, damage to adjacent lands and water-courses and so forth.

(3) Land tailings areas are susceptible to erosion by precipitation and wind etc.

(4) Current technology does not permit complete control of all undesirable substances found in a tailings area decant or in tailings area seepage.

(5) There is an element of inflexibility built into many land tailings areas with regard to storage capacity. As dams etc., increase in height, the risk of tailings area failure etc. also increases.

(6) Chemical waste treatment facilities that may operate in conjunction with a land tailings disposal area can produce large volumes of stable or unstable sludge. This chemical sludge is often highly contaminated and presents a disposal problem of its own.

(7) If care is not taken, a land tailings disposal area can be accidentally sited on a groundwater recharge area. If this happens, contaminated solutions from the tailings area could enter the local or regional groundwater system.

(8) Mineral tailings often include reactive substances (eg: iron sulphides) that undergo chemical changes when exposed to the atmosphere. Extremely serious environmental problems such as acid drainage can result. In addition, mineral tailings can include substances such as asbestos which, under some circumstances, are known to have or to cause adverse environmental effects. In a poorly managed area, such substances can escape containment.

(9) The stabilization by revegetation of abandoned tailings areas can, in some cases, be difficult and expensive. Where stabilization techniques fail, the spectre of chemical waste treatment in perpetuity arises.

(10) During its active life and upon abandonment, a land tailings area can be and usually is visually displeasing to the public unless extreme care is taken.

Most of the disadvantages of a dry land tailings storage site are related to economics.

(C) The Advantages of Underwater (Deepwater) Tailings Disposal

(1) Once tailings transportation facilities to a well-chosen deepwater site have been established, the costs of operating and maintaining the site can be very low. In extreme cases, there may be no cost. This is the main advantage of underwater tailings disposal.

(2) Many deepwater sites can provide an almost limitless tailings storage area.

(3) Tailings deposits in deepwater sites are not in direct contact with the atmosphere. It is logical to assume, therefore, that chemical reactions occurring at land tailings sites

between reactive tailings particles such as the iron sulphides and atmospheric oxygen etc., are either subdued or absent in many deepwater sites. To be more specific, it is entirely probable that acid generation problems due to reactions involving sulphide gangue minerals in situ in tailings masses could be largely eliminated by utilizing proper deepwater tailings disposal procedures (in either salt water ((preferable because of its alkaline nature)) or in fresh water).

(4) Deepwater tailings disposal sites, in general, do not rely on or involve entities such as tailings dams or decant facilities. As such, at a deepwater site, there is very little that can go wrong in a mechanical sense. Submarine slumping probably occurs frequently at an active deepwater tailings disposal site but, in terms of the physical danger it may create, is of little consequence.

(5) When a properly managed deepwater site has been abandoned, the tailings mass is completely hidden from human eyes. There is no visible change to the landscape. In addition, stabilization procedures such as (marine) revegetation are not normally carried out or required.

Most of the advantages of a deepwater tailings disposal site are related to economics.

(D) The Disadvantages of Underwater (Deepwater) Tailings Disposal

(1) A land tailings disposal site acts to divide a tailings slurry into a liquid phase and a solid phase. The solid phase is retained on land where it can be stabilized and the liquid phase is generally decanted to a treatment facility where the toxic components of the phase can be removed before the phase is directed to a watercourse or back to a mill for re-use. On the other hand, in an underwater tailings disposal scheme, the liquid and solid phases of the tailings slurry remain combined up to and including the time of discharge to the receiving watercourse. The liquid phase does not pass through a waste treatment system before discharge to the watercourse and the solid phase is not stabilized before discharge to the watercourse.

In certain rare cases, depending on the type or ore being mined and on the milling process being used, the liquid and/or the solid phase of the tailings slurry may be non-toxic.

However, in most cases, the liquid phase of the slurry can be very toxic due to entrained mine-mill reagents etc. (ref.12) and the solid phase commonly contains substances that are known to display adverse environmental characteristics when suitable conditions present themselves.

(2) A properly designed land tailings disposal site serves to rigidly restrict the movement of tailings particles after they have been discharged to the tailings area. Coarse and fine particles alike remain within the designated boundaries of the area even upon abandonment. At an underwater site, however, the tailings particles are not rigidly confined and are generally free to find their own resting place on the bottom of the sea or lake etc., that forms or is part of the underwater disposal site. Unlike coarse particles that tend to settle out close to the slurry discharge point, fine particles of varying chemical composition can migrate great distances from their point of origin and, in general, contribute to increased turbidities, toxicities and discolouration of area waters. Given equal slurry feed rates it might also be said that, in general, a land disposal site will physically cover (engulf) less area than an underwater site.

(3) The direct discharge of tailings to a receiving water (stream, river, lake or salt water body) can have a large number of direct impacts on the local or regional fisheries resource:

(i) fish spawning areas or shellfish beds etc., may be physically destroyed or damaged

(ii) aquatic organisms and plants etc., which are part of the food chain for fish may be destroyed or damaged

(iii) prolonged exposure to abrasive particles in suspension may cause gill damage in fish

(iv) the toxic components of a tailings slurry may cause lethal and adverse sub-lethal effects in fish

(v) the tissue of local fish and shellfish may be characterized by abnormal concentrations of metals or radioactive substances derived from the tailings mass

(vi) the taste of fish flesh may be impaired due to components of the mine wastes and so forth

(4) Adverse environmental conditions can always develop after a tailings mass has been abandoned. The relatively easy accessibility of an abandoned land tailings mass facilitates any environmental control measures that may be required. However, once mineral tailings

have been discharged to a deep sea or deep lake site, there is very little opportunity to control any detrimental conditions which may develop. It is also premature to suggest that man has assembled all necessary knowledge concerning the possible interactions between tailings particles and the aquatic environment.

There is a third tailings disposal technique that has commonly been used. Referred to as "land-water" disposal, this procedure applies some of the principles of land tailings disposal to a water site. Commonly, a pervious dam is built across a lake or across the mouth of a bay etc., and the area behind the dam is treated as a land disposal site. Normally, as tailings accumulate, the area behind the dam is converted to dry or relatively dry land.

In many cases where a land-water site has been adopted for use, its use represents a compromise between the parties concerned. Since the characteristics of any compromise are such that neither party is totally satisfied nor totally dissatisfied, land-water sites should not be used when they can be avoided.

(E) The Advantages of a Land-water Tailings Disposal Site

(1) The principal advantage of a land-water tailings disposal site is that, in many cases, a large volume disposal area can be created by the construction of a relatively short dam or relatively short lengths of dams. This advantage can be partially offset, however, by the fact that the dam or dams in question must be built in water and, in some cases, in great or varying depths of water. Stated in other terms, the principal advantage of most land-water tailings disposal sites is that such sites are generally more economical to construct and to operate than most land disposal areas of equal volumes. On the other hand, a land-water site is generally more expensive to construct and operate than a deepwater site.

(2) Unlike a deepwater tailings disposal site, a land-water site does serve to confine solid tailings within a reasonably well-defined area.

(3) Before its use as a tailings disposal site, a land-water site is all or predominantly water. Therefore, the usual practice of

clearing vegetation (trees etc) from a land disposal area before use need not be followed at a land-water site.

(F) The Disadvantages of a Land-water Tailings Disposal Site

(1) The use of this type of tailings disposal site normally results in the physical destruction of a section of a natural watercourse.

(2) The pre-operational construction of dams in or across a watercourse can result in the physical and/or chemical impairment of the water. In addition, such dams can change water circulation patterns and fish migration routes etc. in the body of water in question.

(3) Since only a pervious dam separates the tailings area from the water to be protected, waste discharges normally take place directly into the receiving watercourse. That is, the tailings area decant routinely discharges directly into the receiving watercourse as does the seepage that can penetrate the pervious dam along its entire length. Equalization of hydrostatic heads on either side

of a pervious dam in water can serve to minimize seepage through the dam but, in practice, truly equal hydrostatic heads are seldom achieved.

(4) Normal land practices such as seepage collection for treatment cannot be followed at a land-water site since most seepage occurs beneath the surface of the receiving water itself. Also, at land sites, it is now customary to direct decant overflows to downstream polishing areas for final treatment. At a land-water site, however, downstream areas are all under water. Hence, the construction of downstream polishing ponds etc., requires a further physical and/or chemical disturbance of the receiving water. One alternative, of course, would be to direct the decant overflow from a land-water site to a land-based treatment system.

(5) A tailings dam failure usually results in an immediate discharge of tailings to the receiving watercourse. With the possible exception of dredging (which creates its own environmental disturbance) little can be done to clean up such a spill. In fact,

small continuous spills of tailings could go undetected for great lengths of time (particularly during the winter in Canada when the receiving watercourse may be covered with ice).

(6) As a land-water storage site reaches its storage capacity, the area behind the dam is converted to dry or relatively dry land. As such, most land-water sites are ultimately plagued with the environmental problems of most land sites. Blowing tailings and contaminated surface run-off are common. Stabilization (by revegetation) of abandoned areas is usually required.

(7) Tailings dams located in water must be protected against the erosive forces of wave action etc.

(8) When the greater part of a tailings dam is under water (ie. hidden by water), meaningful inspection and maintenance of the dam itself becomes difficult.

DRY LAND; LAND-WATER; DEEPWATER TAILINGS DISPOSAL WHICH IS BEST?

All methods of tailings disposal are equally bound by the confines of present day technology and by the day-to-day realities of economics and politics. However, even in the context of the above restrictions, certain general environmentally-oriented statements can be made concerning the methods of tailings disposal that are currently available:

A. With regard to long-term accessibility of deposited tailings:

(i) dry land methods offer maximum accessibility

(ii) land-water methods offer moderate accessibility

(iii) deepwater methods offer minimum accessibility

B. With regard to control (chemical and/or physical treatment) of decant and seepage wastes:

(i) dry land methods offer maximum control

(ii) land-water methods offer moderate to a low degree of control

(iii) deepwater methods offer minimum control

C. With regard to the protection of the receiving watercourse (assuming all three methods are carried out properly):

(i) dry land methods offer maximum protection

(ii) land-water methods offer moderate to low protection since these methods imply the physical destruction of portions of a natural watercourse and essentially no treatment of the aqueous phase of the slurry

(iii) deepwater methods offer low protection since these methods use the receiving watercourse as the disposal medium

D. With regard to aesthetics:

All three methods of tailings disposal present aesthetic problems. Dry land and land-water schemes generally result in highly visible accumulations of tailings. Deep-water schemes commonly give rise to massive turbidity problems in the receiving watercourse especially if the tailings contain a coloured slime fraction.

Aesthetic problems associated with dry land and land-water schemes can be reduced or eliminated by the use of "common sense" engineering coupled with revegetation projects that span both the active and abandoned phases of mining.

Aesthetic problems associated with deepwater disposal are commonly resolved when the mining operation is abandoned and all turbidity-producing particles settle or disperse. Tailings hidden under a deep blanket of water are, however, soon forgotten. The "out of sight - out of mind" result which is a common inherent characteristic of deepwater tailings disposal schemes does present specific dangers. Physical/chemical reactions of tailings particles in contact with water for great lengths of time cannot be easily predicted. If a problem is identified, its solution is extremely difficult.

In summary, dry land tailings disposal schemes generally offer the possibility of maximum environmental control under a given set of conditions. Land-water schemes normally offer a much decreased possibility of control and deepwater schemes, in most cases, offer little possibility of control.

TAILINGS DISPOSAL RESTRICTIONS

A. Deepwater Disposal Schemes

Certain specific restrictions should be placed on the use of deepwater tailings disposal sites:

(i) upon abandonment of the mining operation and/or the tailings disposal site, all deposited tailings should rest considerably below the depth of turbulence caused by surface wave action and should not be in an area subject to scouring by submarine currents.

(ii) at least 50 meters of water should lie above the deposited tailings upon abandonment of the site

(iii) the discharge point of a tailings line feeding a deepwater site should be located below the surface of the receiving water and should be below the maximum depth of turbulence caused by surface wave action etc.

(iv) tailings containing mobile coloured slime fractions (eg. hematite, limonite, goethite) should not be deposited in deepwater sites

(v) tailings containing significant quantities of releasable substances that are regarded as detrimental to human life and/or are re-

garded as detrimental to aquatic fauna and/ or flora should not be deposited in deep-water sites. Such substances include:

asbestos (chrysotile and/or amphibole)
mercury
cadmium
copper
lead
zinc
nickel
cyanide
radioactive materials (eg. radium, thorium)

B. Land-water Disposal Schemes

Certain specific restrictions should be placed on the use of land-water tailings disposal sites:

(i) tailings containing significant quantities of releasable substances that are regarded as detrimental to human life and/or are regarded as detrimental to aquatic fauna and/or flora should not be deposited in land-water sites unless:

a) the dam separating the tailings area from the receiving watercourse is impermeable and;

b) the tailings area decant serving the tailings area is directed to a "downstream" facility (preferably on land) for any required chemical and/or physical treatment

The substances referred to in this item include:

asbestos (chrysotile and/or amphibole)
mercury
cadmium
copper
lead
zinc
nickel
cyanide
radioactive materials (eg. radium, thorium)

(ii) tailings containing mobile coloured slime fractions (eg. hematite, limonite, goethite etc.) should not be deposited in land-water sites unless effective colour-removal techniques are to be practiced and the general conditions (i)(a) and (i)(b) above have been met.

(iii) the tailings area should be revegetated before being abandoned

C. Dry Land Disposal Schemes

The restrictions that are commonly placed on dry land tailings disposal areas differ fundamentally from those placed on land-water and deepwater sites in that essentially any volume of tailings of any physical or chemical nature may be stored on land providing that approved and proper safety, health and land disposal techniques are rigidly adhered to.

The techniques that are used to achieve satisfactory environmental results at dry land tailings disposal sites vary locally, regionally, nationally and internationally and are greatly influenced by climate, economics and politics.

S U M M A R Y

When mineral tailings are directed to a properly engineered land storage site, maximum environmental control is possible. Although limited by the imperfect state of our present-day technology, treatment can be provided for both the aqueous and solid phases of the tailings slurry.

In routine situations, only a moderate degree of environmental control is possible at land-water tailings disposal sites. Control of the aqueous phase of the tailings slurry is a major problem.

Deepwater tailings disposal sites offer only minimum opportunities for environmental control. In the majority of cases, both the liquid phase and the solid phase of the tailings slurry remain uncontrolled.

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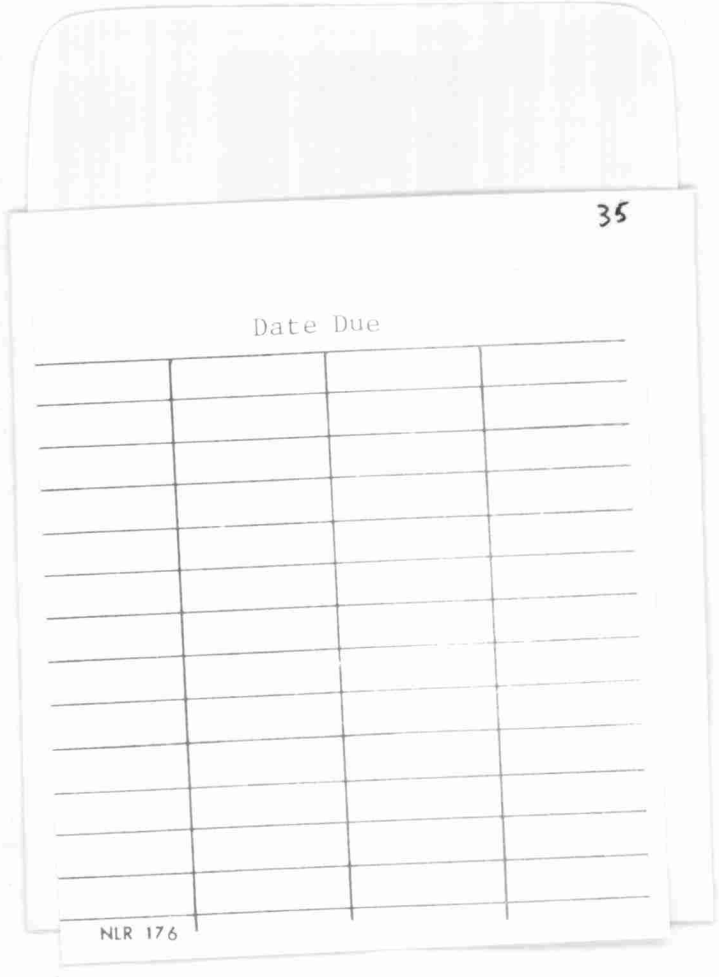
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